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TNO-report

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SPACE ADAPTATION SYNDROME INDUCED BY A LONG DURATION +3Gx CENTRIFUGE RUN

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ABSTRACT

The three European scientist astronauts of the D1 Spacelab Mission were exposed to a 1 1/2 hours +3G centrifuge run in supine position result ng in a linear acceleration along the x-axis (3Gx). Afterwards they experienced motion sickness symptoms which were for each of the astronauts similar to the symptoms of the Space Adaptation Syndrome as experienced during their space flight in 1985. These motion sickness symptoms lasted up to 6 hours. In otolith function tests following the centrifuge run, changes in visual-vestibular interaction were observed which replicated findings obtained immediately after their space flight.

Rap. IZF 1989-25

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Ruimteziekte opgewekt door een langdurige belasting van +3Gx in de centrifuge

W. Bles, J.E. Bos, R. Furrer, B. de Graaf, R.J.A.W. Hosman, H.W. Kortschot, J.R. Krol, A. Kuipers, J.T. Marcus, E. Messerschmid, W.J. Ockels, W.J. Oosterveld, J. Smit, A.H. Wertheim en C.J.E. Wientjes

SAMENVATTING

De drie Europese wetenschaps astronauten van de D1 Spacelab Mission zijn gedurende 1 1/2 uur blootgesteld aan een 3G centrifuge run in rugligging resulterend in een lineaire versnelling langs de x-as (3Gx). Naderhand ervoeren zij bewegingsziekte symptomen die voor ieder van de astronauten overeenkwamen met de symptomen van het Space Adaptation Syndrome zoals zij die tijdens hun ruimtevlucht in 1985 ervaren hadden.
Deze bewegingsziekte verschijnselen duurden ongeveer 6 uur.
Bij onderzoek van de otoliet functie na de centrifuge run werden veranderingen in de visueel-vestibulaire interacties waargenomen die overeenkwamen met bevindingen onmiddellijk na hun ruimtevlucht.

1 INTRODUCTION

Since the size of spacecraft allowed astronauts to move around (USSR's Voskhod, Salyut and Mir; US' Apollo, Skylab and STS) about 40 % of the astronauts encountered a type of motion sickness, also called "Space Adaptation Syndrome" (SAS), during the first days of the flight (Homick et al., 1984; Thornton et al., 1987). Although the symptoms in general are similar to earthbound motion sickness, no correlation has been found between individual susceptibility to motion sickness provocation tests on earth and susceptibility to space sickness (Reschke et al., 1984). It has been argued therefore that the underlying cause of the Space Adaptation Syndrome and the more common types of motion sickness (sea sickness, air sickness etc.) might be different. There is, however, general agreement about involvement of the vestibular system, and particularly the otolith system, in the aetiology of space sickness, because of the microgravity surround.

Since the success of a mission in space relies on crew well-being and optimal task performance (and should therefore not be hampered by space sickness) many investigations in space and on the ground have been directed to the function of the otolith system, using a.o. the ESA sled in Spacelab, but no distinct clue was found to the aetiology of SAS or individual susceptibility and predictability (von Baumgarten et al., 1987; Oman et al., 1986). One of the problems in this research area was that studying adaptation of otolith functions to the microgravity environment seemed to be limited to research in space itself. By coincidence, however, it was found that similar adaptation phenomena develop after exposure to a higher G load.

Long duration +G load experiments have been performed on the human centrifuge at the Netherlands Aerospace Medical Centre, Soesterberg (November 1988, unpublished data). The original scientific objective was to investigate the response of the human immune system after the studies of Cogoli and Lorenzi (Cogoli et al., 1986; Lorenzi et al., 1986). A +Gx load was applied to minimize circulatory complications. The duration of this Gx load was 1 1/2 to 2 hours. Medical monitoring during the runs did not reveal any serious health problem, but the runs gave rise to the development of epigastric awareness and slight nausea. After completion even stronger vestibular effects were observed. These effects persisted for more than 6 hours, and consisted of perceived floor motion, balance difficulties and provocation of symptoms by movements in the vertical plane. No nystagmus was observed nor provocation due to fast head movements in the horizontal plane. One subject vomited 45 minutes after the run was completed and did so a few times more until going to bed 6 hours later. The next morning there were still some residual symptoms subsiding only in the course of the day. Another subject, W.J. Ockels, also experienced strong readaptation symptoms persisting over a long period after the run. The overall symptoms and perception were similar to W.J. Ockels' space adaptation syndrome experience.

The present study was therefore designed to expose the European scientist astronauts of the 1985 D1 Spacelab Mission (W.J. Ockels, R. Furrer and E. Messerschmid) to a long-duration Gx load in the centrifuge with the objective to compare the individual susceptibility for the readaptation effects after the centrifuge run (transition from 3G to 1G) to their experience of the Space Adaptation Syndrome (transition from 1G to 0G). Apart from rating their adaptation sickness, they were also subjected to an Otolith Function Test Battery in order to look for changes in the functioning of the otolith system. This battery comprised tests of the otolith function in linear object motion perception (on the ESA sled), in postural control and perception of the vertical (with stabilometry and the Tilting Room), in the modulation of the OKN by linear acceleration (on the ESA sled), in the VOR by caloric examination, and tests on task performance. The battery was administered just before the centrifuge run to obtain baseline values, immediately after the centrifuge run and a couple of hours later to study retention.

The set-up of the experiments is described in section 2. The details of the centrifuge run and those of the medical monitoring are described in section 3. Section 4 deals with the motion sickness experience of the subjects. In sections 5 - 9 the experiments of the Otolith Function Test Battery are described. Discussion and conclusions are dealt with in sections 10 and 11.

2 METHODS

2.1 Centrifuge run

The three astronauts (A, B and C) were exposed to a 3G load for 1 1/2 hours in the centrifuge of the Netherlands Aerospace Medical Centre. Since they were in supine position they encountered a linear acceleration in the x-

Table 2.1 Time scedule of the centrifuge run.

time (hrs)	
00.00 – 00.15	Preparation med. monitoring Med. check-up + Stabilometry I Vital Capacity I, interview
00.15 – 00.45	Centrifuge Run I -30 min
00.45 – 01.00	Vital Capacity II Med. check-up II Stabilometry II , interview
01.00 – 01.30	Centrifuge Run II -60 min
01.30 – 01.45	Vital Capacity III Med. check-up III Stabilometry III , interview
01.45 – 02.15	Centrifuge Run III -90 min
02.15 – 02.30	Vital Capacity IV Med. check-up IV Stabilometry IV , interview

direction (3Gx). Acceleration and deceleration rates were 0.1 G/s. The run was split up in parts of 30 minutes for optimal control of the subject's health (medical check-up and measurement of the vital capacity of the lungs, see section 3), for measurement of postural stability (see section 6) and an interview for grading possible motion sickness symptoms (see section 4).
The time scedule of the centrifuge runs is shown in Table 2.1.

2.2 Otolith Function Test Battery

The Otolith Function Test Battery was administered at the TNO Institute for Perception. The time line of the tests is shown in Table 2.2. The order of the tests was chosen in such a way that the most provocative tests were

Table 2.2 Time scedule of the Otolith Function Test Battery

time (hrs)		
00.00		
.05		
.10	Linear Motion	(ESA Sled)
.15	Perception.	
.20		
.25		
.30		
.35	Stabilometry,	(Tilting Room)
.40	Tilting Room,	
.45	Spatial Perception.	
.50		
.55		
01.00		
.05	OKN	(ESA Sled)
.10		
.15		
.20	Performance	(TASKOMAT)
.25		
.30		
.35		
.40		
.45	Caloric	(Tilting Room)
.50	Examination	
.55		
02.00		

placed at the end. The Tilting Room Test, however, was positioned in between the two Sled tests in order to gain time for repositioning of the Sled carriage.

2.3 The Experiment

The experiment started with the administration of the Otolith Function Test Battery to determine baseline values. Subsequently the astronauts were transported from the TNO Institute for Perception to the neighbouring Netherlands Aerospace Medical Centre (NLRGC) for their centrifuge runs. Afterwards they were brought back again for the second Test Battery. After this test they could relax a little until they were examined once more in the Test Battery (see Table 2.3).

Table 2.3. Time scedule of the experiment for each of the astronauts.

time (hrs)	
00.00	
00.30	Training Taskomat
01.00	+
01.30	Otolith Function
02.00	Test Battery I
02.30	
03.00	
03.30	
04.00	Centrifuge Runs
04.30	
05.00	
05.30	
06.00	
06.30	Otolith Function
07.00	Test Battery II
07.30	
08.00	
08.30	
09.00	
09.30	
10.00	
10.30	
11.00	
11.30	Otolith Function
12.00	Test Battery III
12.30	
13.00	

To each astronaut two observers were assigned to serve as a guide during the experiments, to take care of their well-being. The NLRGC took care of the usual medical supervision during the centrifuge runs, DLR (Koln) supplied medical supervision during the Otolith Function Test Battery.

3 CENTRIFUGE RUN

J.R. KROL

3.1 Introduction

This section shortly describes the centrifuge part of the experiment with emphasis on the pulmonary and cardiovascular responses during the centrifuge runs.

3.2 Methods

During the centrifuge runs the astronauts were in a nearly recumbent position with the main G-vector in the direction of the X-axis of the body. It was advised to avoid head movements. The acceleration and deceleration rate of the centrifuge was 0.1 G/sec. The total G-load was +3 Gx for 90 minutes. The run was interrupted at 30 minutes intervals for measurement of Vital Capacity (VC), a physical examination of the lungs, stabilometry and a motion sickness score (Graybiel scale) (Table. 2.1). The interruptions lasted maximally 10 minutes. During the runs and approximately 1 minute before and after the following parameters were continuously monitored: oxygen saturation of arterial blood (SaO2), heart rate (HR), systolic blood pressure (BPs), diastolic blood pressure (BPd) and the beat to beat blood pressure curve (Finapres pulse) (not presented here). All measurements were non-invasive. In addition an electrocardiogram was recorded.

The equipment used for the measurements of the pulmonary and cardiovascular parameters consisted of: Vicatest (Mijnhardt) for VC, Pulse Oximeter (Ohmeda) for SaO2 and Finapres Model 5 (TNO/BMI) for HR, BPs, BPd and Finapres pulse. Finapres measurements were made using a fingercuff at approximately heart level. The SaO2 sensor was clipped to an earlobe. There was voice contact and visual contact via intercom and a video camera in the centrifuge gondola.

3.3 Results

Figure 3.1 shows a typical result of SaO2 (upper panel), HR (middle panel) and systolic and diastolic blood pressure (BPs and BPd, lower panel) measurements. As a reference the G-profile is drawn in each panel. The run number refers to the first 30 min. profile. The time scale is in minutes.

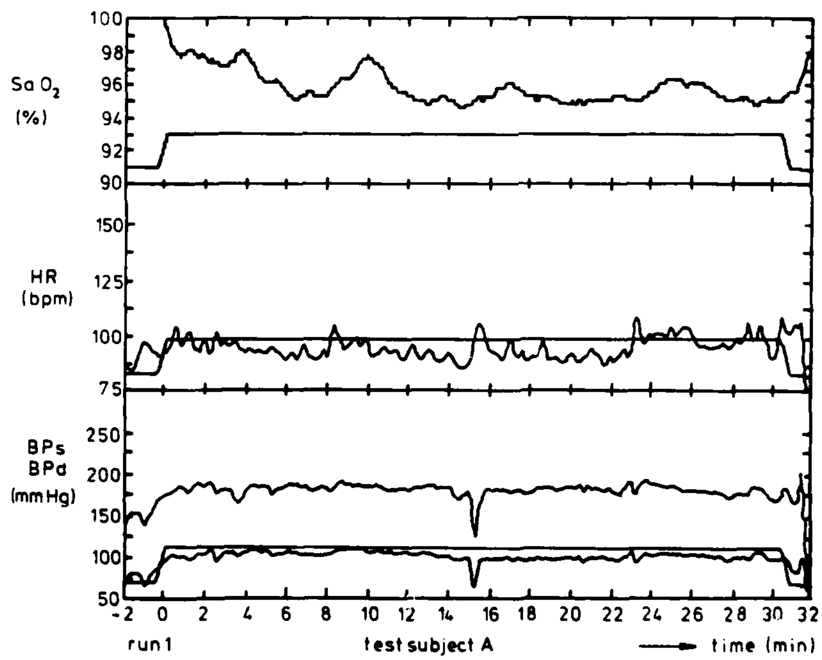

Fig. 3.1 Results during the first 30 minutes run of test subject B. Upper panel: Oxygen saturation of arterial blood (SaO_2), middle panel: heart rate (HR), lower panel: systolic and diastolic blood pressure (BPs and BPd). In each panel the Gx profile is indicated.

All runs showed a fall in SaO2 during G-load to a level near or slightly below 95%, with no further decline throughout the runs. After cessation of the G-load the SaO2 values returned to normal. HR increased moderately to values between 90 and 125 bpm. BP showed a moderate to substantial increase. Fig. 3.1 shows a sudden fall in BP between 15 and 16 minutes, probably as a result of lifting the arm connected to the Finapres (hydrostatic effect amplified by G-load). VC before the run, during the stops and after the last G-profile did not show significant changes. Physical examination of the lungs did not reveal abnormalities. One test subject showed occasionally premature ventricular contractions on the ecg monitor during G-load.

3.4 Discussion

The most striking finding was the fall in SaO2 to hypoxia level (95% or slightly less). General causes of hypoxia are low PiO2, alveolar hypoventilation, diffusion abnormalities, shunting, ventilation-perfusion heterogenity, hemoglobin abnormalities, low cardiac output. Among these causes the following may be applicable: hypoventilation, diffusion impairment, ventilation-perfusion heterogenity, right to left shunt and diminished cardiac output. From this list diffusion impairment caused by pulmonary oedema was of most concern. Increased hydrostatic pressure in a great area of pulmonary vasculature during a long time could give rise to extravasation of fluid into lung tissue and alveolar spaces. However, we did not find down sloping SaO2 values in the course of the 90 minutes and after each stop the SaO2 values returned to normal values within a short period of time, which argues against the development of pulmonary oedema. Furthermore we did not find a significant decline in VC and physical examination revealed no auscultatory abnormalities. However, we cannot exclude the accumulation of small amounts of fluid in the pulmonary tissues by these methods. Hypoventilation could have played a role because of an impairment of ventilation by pressure on the thorax, but we feel that a normal tidal volume and respiration rate can be maintained during +3 Gx. The absence of pooling, the relative moderate HR increase and increased BP argue against a reduced cardiac output. The most likely explanation of the drop in SaO2 is ventilation-perfusion inequality and right to left shunt. Experiments in the past (12, Glaister DH, et al.) have shown these changes in blood flow

in different levels of the lung (decrease in the upper parts and increase in the dependent parts) and a ventilation impairment in the dependent parts. Figure 3.2 shows the effect on ventilation and perfusion at +5 Gx. The ideal Va/Q (Va = ventilation, Q = perfusion) equals 1. The figure shows the inequality in favour of ventilation in the anterior part of the lung and an inequality in favour of perfusion in the posterior part. The most posterior part shows no ventilation at all, creating a right to left shunt (unsaturated blood bypassing the lung). Figure 3.3 is an illustration of the effect of different +Gx-loads (less than 6 minutes) on SaO2 and indicates the possible profound effects on pulmonary function.
In conclusion we may state that it is highly unlikely that the reported motion sickness is of cardio-vascular origin.

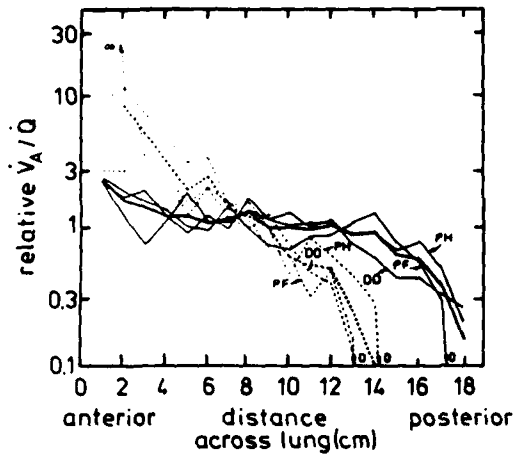

Fig. 3.2 Relation between ventilation and perfusion at 5G (From Glaister, D.H., AGARDograph 133)

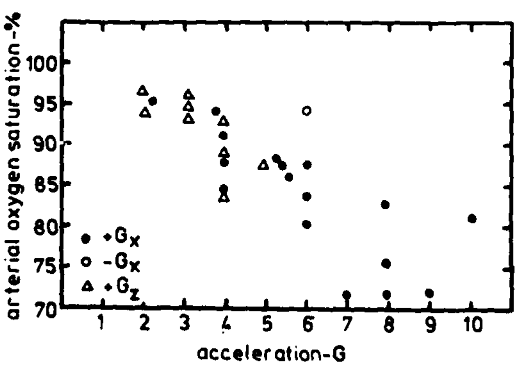

Fig. 3.3 Effects of different G-loads on SaO_2. (From: Glaister, D.H., AGARDograph 133)

4 MOTION SICKNESS

B. de Graaf and A. Kuipers

4.1 Method

The severity of motion sickness symptoms was scored on the Graybiel scale (Graybiel et al, 1968) according to the concordant judgement of two observers. They scored objective symptoms like pallor, sweating, drowsiness and increased salivation in a very conservative way (to prevent unlogical high outcome on the Graybiel scale). The additional subjective feelings of nausea were reported by the subjects. Epigastric discomfort was scored as 2 points, mild nausea as 4 and the moment the subject mentioned that he had reached the point where he had to find strategies to prevent rapidly increasing symptoms (like vomiting) was scored as 8 on the Graybiel scale. Vomiting was scored as 16 points.

After each of the 3Gx runs the subject came out of the centrifuge for a medical check-up, stabilometry and a short interview (see Table 2.2). After the centrifuge runs the subjects were scored every 30 minutes, but also when a specially provoking event had taken place during the test sessions. Besides motion sickness symptoms the subjects were asked for their other experiences, and to compare these with the problems they had during their spaceflight.

4.2 Results

During the centrifuge runs two of the subjects already scored a severe malaise on the Graybiel scale. All three subjects mentioned an increased susceptibility for movement, which was already evident after the first 30 min. run and cumulative for the two subsequent runs. Linear movement along the z-axis (knee bending), but specially head rotation round the y-axis (nodding) and to a lesser extent head rotation round the x-axis (lateral tilting) led to sensations of environmental motion and corresponding postural (over)reactions. In a static situation the subjects had no such problems but the onset of movements was highly provocative for motion sickness symptoms. The subjects therefore prevented any head movement and walked upright and slowly, while keeping a stiff neck. The astronauts repeatedly mentioned experiences familiar to them from their stay in space, during 2G walking and after returning to earth. Pitching head movements led to strong vertical nystagmus accompanied by oscillopsia. Ascending a staircase gave the sensation of pushing down the steps and walking more or less horizontally (cf. readaptation from space, Young et al., 1986).

During the following sessions in the Otolith Function Test Battery there were several provoking situations, which all added to a feeling of severe malaise in two of the subjects. Active or passive head movements while getting in and out of a testing device, visual stimulation in a tilting room and caloric stimulation of the vestibulum led to motion sickness symptoms. This was, however, not the case in the baseline measurements.

One subject (B) had his highest Graybiel score after completion of the third centrifuge run and his severe malaise decreased rapidly to a moderate level during the rest of the testing day (see Fig. 4.1). During the centrifuge run he complained about some pain in the back, probably caused by the non optimal support given to the back.

Subject A experienced few symptoms of motion sickness during the centrifuge runs, but the provoking moments in the test sessions added up to a level of severe malaise where he had to find strategies to prevent vomiting. This lasted for a long period.

Subject C reached a level of severe malaise soon after the beginning of the centrifuge runs which persisted for many hours with two periods of frank sickness (vomiting), respectively 2 hours and 6 1/2 hours after the last centrifuge run. In the latter case this happened when C tried to fix his shoelace.

The strength of the motion sickness symptoms depended on the strategy of the subject, i.e. the willingness to move the head or to participate in the tests. For example, it took subject A over 4.5 hours after the centrifuge run before he was willing to nod his head cautiously for 10 times (but not more). The same subject had twice to stop the conduct of vestibular tests as to avoid frank sickness. Subject C participated more actively which resulted in two periods of frank sickness (vomiting). The curves representing the adaptation syndrome (see Fig 4.1) show a clear difference in adaptation between subject B who reached the highest point at the end of the centrifuge run and the two other subjects, A and C, who build up the

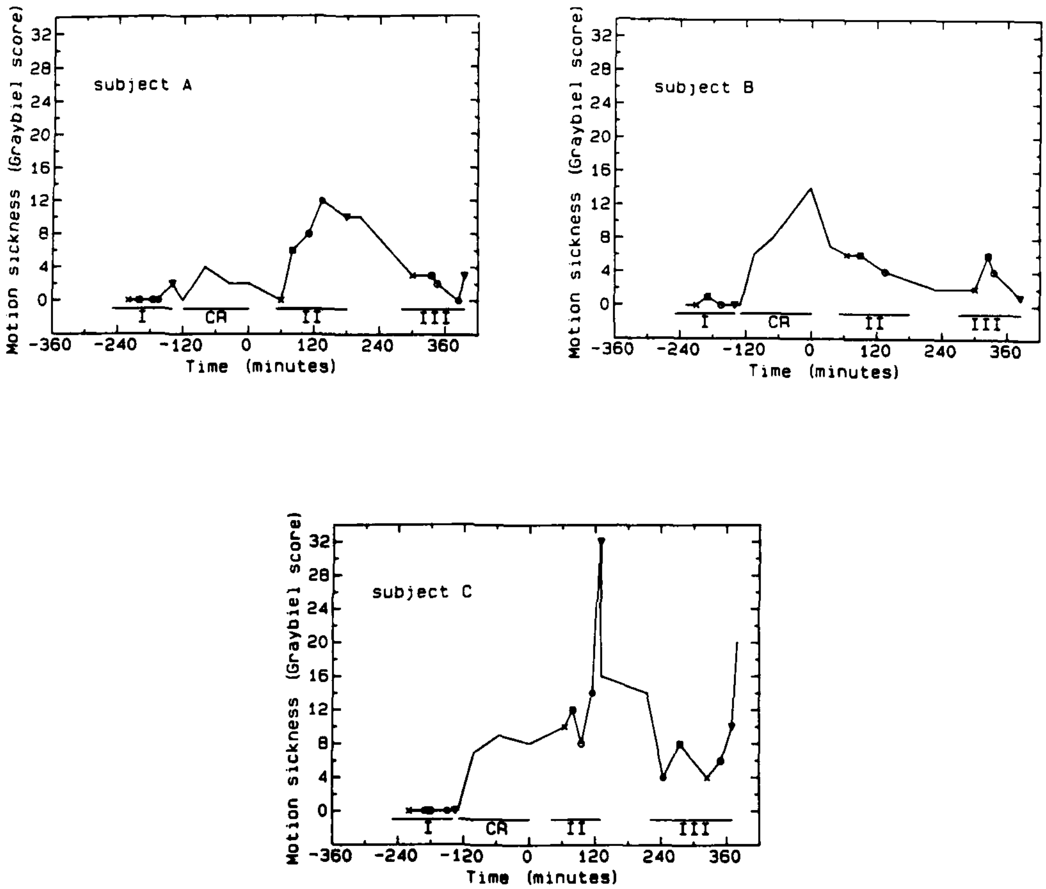

Fig. 4.1 The course of motion sickness before, during and after the prolonged 3Gx centrifuge run. Each panel corresponds to the score on the Graybiel scale for one astronaut. The zero point on the X-axis stands for the moment the astronauts finished the complete centrifuge run (CR), which had started approximately 2 hours before. I, II and III stand for, respectively, the pre-exposure test battery, the first and second post-centrifuge test battery. The symbols represent the values scored directly <u>after</u> a particular test: x - visual motion-perception, • - stabilometry and tilting room, ∘ - OKN modulation• - task performance, ∇ - caloric examination (See Table 2.1). Nota Bene, with a score between 8 to 15 points on the Graybiel scale of motion sickness the subject is assumed to endure a severe malaise, and with 16 points or more to suffer from a frank sickness.

malaise over a long period of time. This behaviour corresponds well with the individual differences experienced in adapting to weightlessness.
For one of the subjects (B) hand writing was disturbed after the centrifuge run, but this was not the case in the two other subjects: one of them could play the piano without missing too many notes. Six hours after the centrifuge run subject B played a game of table tennis, while the two others did not even dare to think about that.

4.3 Conclusions

The effects of the prolonged 3Gx stimulation were very specific and lasted much longer than usual in motion sickness. Linear head movements along the z-axis and rotation around the x- and y-axis led to increased sensations of movement and were prevented because of provocation of motion sickness symptoms. Scoring constantly high on the Graybiel scale was impaired by (the possibility of) these defensive mechanisms. Nevertheless, despite the strategy used by the astronauts to stay as static as possible and the rather static character of the tests they underwent, the subjects suffered a kind of motion sickness which was, as they said, quite comparable with some of their problems in space.

5 VISUAL MOTION PERCEPTION

A.H. Wertheim and R.J.A.W. Hosman

5.1 Introduction

An important feature of the SAS is that during selfmotion, illusory movement of the visual world (oscillopsia) may be perceived. Normally this does not occur, because the perceptual system uses a decision rule to interpret the meaning of retinal image motion. Movement is only perceived when a difference is detected between the retinal signal, encoding the sweep of the visual world's image across the retinae, and a so called reference signal, in which the concurrent movement of the eyes in space is encoded. Usually the two signals are equal, which for the visual system implies that the image motion is self-induced and consequently the world is perceived as stationary (see e.g. von Holst and Mittelstädt, 1950; Sperry, 1950; Matin, 1982; Mittelstädt, 1989; Wertheim, 1987,1989).

The retinal signal is presumably derived directly from simple velocity detectors. The reference signal, however, is a compound signal, constructed from various components, which in turn derive from afferents encoding the movements of the eyes in their orbits and movements of the subject's head in space ('efference copies', vestibular afferents, visual optic flow and particular kinesthetic information). We propose that the SAS related oscillopsia happens because in microgravity the magnitude of the reference signal is incorrect, its otolith component being abnormally sized. Thus we predicted that loading the otolith system in the x-axis direction in the centrifuge, should also result in a change of reference signal magnitude and cause oscillopsia.

The magnitude of an otolith composed reference signal can be assessed by moving an observer linearly, while presenting him with a visible stimulus pattern that can be moved by an experimenter until the subject reports that the pattern appears to be stationary. At this Point of Subjective Stationarity (PSS) retinal and otolith induced reference signals are equal by definition. Hence, at the PSS retinal image velocity can be taken as an index of reference signal size. Such an experiment must be carried out in darkness and with only a briefly visible stimulus pattern, to prevent the development of an additional optic flow component in the reference signal (see Wertheim 1987, 1989; Wertheim and Bles 1984).

5.2 Method

Visual motion thresholds were measured during sinusoidal linear motion of the ESA sled (freq. 0.14 Hz, max. vel. 1.1 m/s). Two video monitors were positioned at eye level opposite to each other on both sides of the sled's track, the distance between their screens being 1 m. The subject, seated on the moving sled, thus moved to and fro between the two screens (see Fig. 5.1). The monitors were positioned at the midpoint of the track, where sled velocity reached its maximum of 1.1 m/s. When, at this point, the subject passed between the monitors, a checkerboard pattern was simultaneously

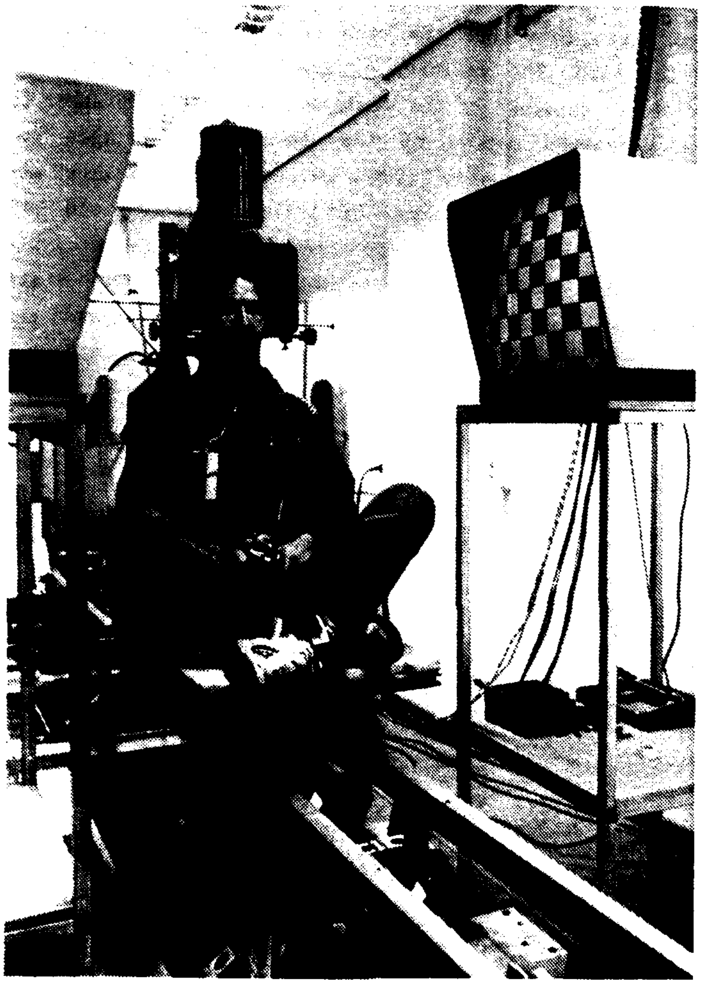

Fig. 5.1: Experimental setup with one of the astronauts seated on the ESA-sled. In his hands a telecom for communication of his verbal responses to the experimenter. The actual experiment was carried out in total darkness.

presented on both of them for a period of only 400 ms (Hosman and van der Vaart, 1989, showed that such a brief interval does not affect retinal signal size).

The patterns moved in either the same or the opposite direction as the subject on the sled. The velocity of the patterns was set anew by the experimenter for each sweep of the sled, and depended on whether or not the subject had perceived motion of the checkerboard pattern during the previous sweep. Thus thresholds for the detection of (absolute) motion were obtained with the staircase method of limits (see Wertheim 1981, 1987; Wertheim and Bles, 1984). The two opposite thresholds (same as sled motion or opposite to sled motion) were obtained during forward and also during backward motion of the sled. Thresholds were also obtained with the sled in stationary position exactly in between the two monitors. All thresholds

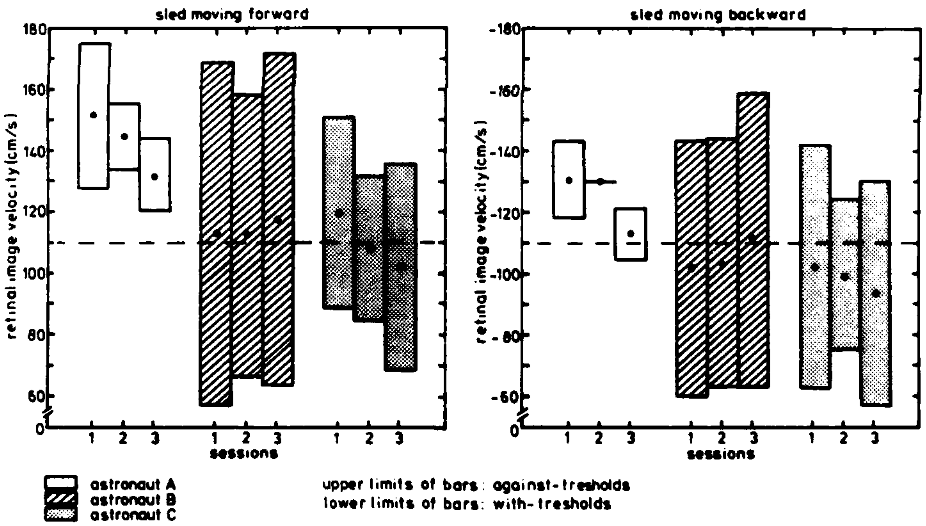

Fig. 5.2: No-motion ranges (bars) between the two opposite thresholds - signifying the noise level within the perceptual system (see section 5.4) - for each of the astronauts at each of the three experimental sessions. The ordinates of the midpoints within the bars represent the size of the reference signals in the respective conditions.

were measured two times and in random order. Subjects were positioned on the sled with their head fixed rigidly to their seat and, to prevent eye movements, they were required to fixate a small LED, placed 4 m. in front of the endpoint of the sled's track. Hence the perception of the checkerboard patterns was always peripheral. EOG was recorded and showed that no saccadic eye movements occurred. All visual references to external space were eliminated by carrying out the experiment in absolute darkness. One complete experimental session took about 30 min. (Table 2.2) and was run once before and twice after the centrifuge run (Table 2.3).

5.3 Results

With the sled stationary, thresholds were less than 0.5 cm/s. and did not differ from each other. The other thresholds, measured during sled movement, are presented in Fig 5.2 (means of the two repeated measurements). The distance between the two opposite thresholds, the no-motion range, is represented by the bars. Since movement is not perceived between the two thresholds, this range represents the amount of noise in the perceptual system. The dots in the bars represent the midpoints between the two opposite thresholds. They thus correspond to retinal image velocity at the exact PSS, and thus reflect reference signal magnitude.

Against our hypothesis no consistent change in reference signal size was found before and after the centrifuge run. Reference signal magnitude did however differ between astronauts: In contrast to the others, A's reference signals were much too large (with one exception). Furthermore, with forward sled motion reference signals seemed to be slightly larger than with backward sled motion, suggesting a direction specific bias in reference signal gain during such otolith stimulation.

With respect to the amount of noise between retinal and reference signals, clear and significant differences existed between astronauts ($p<0.001$, 76% variance explained). As can be seen in Fig 5.2, astronaut B had the largest noise band, A the smallest and C in between. Note that in general A's noise level was too small to mask the large differences which occurred between his retinal and his 'oversized' reference signals. As a result he almost always perceived illusory motion of the checkerboard patterns when they were physically stationary. This is illustrated in Fig. 5.2 by the dotted line, which represents retinal image velocity when the checkerboard patterns are stationary: with one exception the line lies outside astronaut A's no-motion range.

Furthermore, for all subjects the noiseband was smallest at the second session immediately after the centrifuge. However, this effect was rather small (although significant at $p<0.02$), expaining only 5% of the variance in the data.

5.4 Discussion

Surprisingly, no obvious effects of the centrifuge run were observed on reference signal magnitude in the x-direction. Apparently, the otolith contribution to the reference signal had not been changed during the centrifuge run.

A possible explanation is that the magnitude of the reference signal, or more precisely, of its otolith component, was changed indeed, but not its vectorial direction. The point is that this component derives from otolith afferents. With subjects in an upright position (as in our experiment) such afferents constitute a vector pointing primarily in the direction of the gravitational field (z-direction). Hence biases in the magnitude of the otolith component in reference signals would only have become apparent if thresholds had been measured with subjects and stimulus patterns also moving in that vertical plane. Such a hypothesis is in line with the (upright) astronauts reports, that after their centrifuge runs, readaptation symptoms and oscillopsia only occurred when they made vertical eye- head- and ego movements, or rotated their head around the y-axis (in which case a small z-component is present). Self movements along the earth horizontal plane did not induce such symptoms.

As mentioned before, reference signals are compound signals, consisting of many components. Thus it should not be surpiising that even in normal circumstances their gain is not always exactly 1 (see sessions 1 in Fig. 5.2). We propose that the intrinsic noise in the system normally masks the consequent small differences between retinal and reference signals. Only in cases where this noise level is small and the gain of reference signal deviates much from 1, one would expect oscillopsia to occur (as with astronaut A). In this respect the consistent individual differences in noise level between astronauts constitute an interesting finding. It may indicate that more noise implies a higher resistance to oscillopsia, i.e. to space sickness (and possibly also to motion sickness in general). Such a hypothesis agrees with the present results that A's no-motion range was smallest, then C and then B: During their common 1985 space mission, A had suffered most from space sickness, then C and then B. Furthermore, for all subjects the noise band was smallest in the second run (immediately after the centrifuge), which also agrees with the hypothesis, because at this time the readaptation symptoms were most pronounced.

5.5 Conclusions

The main finding of this experiment is that, at least along the earth horizontal axis, the gain of (the otolith induced component in) a reference signal remains unaffected after prolonged 3Gx stimulation. The amplitude of this central response could still be affected, but this may have remained hidden from view during the experiment, because the vectorial direction of this response may be locked to gravity.

The consistent differences observed between the astronauts with respect to their individual noise levels agree with our hypothesis that noise level reflects space sickness susceptibility to the extent that people with low noise levels might be more susceptible to space sickness than those who have high noise levels, especially if the gain of their reference signals also deviates much from 1.

6 SPATIAL PERCEPTION, STABILOMETRY AND TILTING ROOM

W. Bles

6.1 Introduction

Whether a subject is in supine or upright position, the otoliths always sense a gravito-metrial acceleration of a 1G magnitude. Apparently it doesn't matter for the subject's well-being which otolith cells are stimulated as long as the 1G vector remains present. If such a 1G vector is not sensed any more, e.g. after transition to a micro-gravity surround, problems arise in terms of SAS. In view of the pilot centrifuge experiment (section 1) similar problems arise during readaptation from a 3G surround to a 1G surround. The hypothesis was that this might be due to adaptation effects within the (central) otolith system. For the present study we hypothesized, in view of the specific loading in the x-direction, an after effect in the opposite direction (-x) which, together with the 1G vector, would alter the direction of the perceived gravity vector in the midsagittal plane (x,z plane).

In the present experiment on postural control and spatial perception the objective was to establish changes in the otolith function due to the centrifuge run according to this hypothesis.

One approach was to have the subject adjust himself to the upright position, either in the pitch mode (effect expected according to the hypothesis) or in the roll mode (no effect expected), in both conditions of course with the eyes closed.
A second approach was to study postural stability. Vestibular disturbance in postural control is most clear when the eyes are closed and according to the hypothesis instability is expected in the A/P direction; according to Brandt (Brandt et al., 1981) head extension with the eyes closed is a very suitable condition to study otolith function and therefore of interest for the present experiment in view of the alignment of the x-axis of the head and the gravity vector.
The third approach concerns postural stability during a visual-vestibular conflict induced in a tilting visual surround. It was found in earlier

experiments with the same subjects that readaptation to 1G after a period of microgravity could lead to a temporary change in the weighting of the otolith information in favor of the visual information (Bles and van Raaij, 1988). In view of the stimulation in the centrifuge along the x-axis of the subject, instead of the usual lateral room tilt a foreaft tilt was thought to be more appropriate for the present experiment.

6.2 Methods

6.2.1 Subjective Vertical

The subject was seated on a chair in the TNO Tilting Room with his head fixed to the chair. This room (2.5 * 2.5 * 2 m) tilts around an axis just under the floor. The position of the chair allowed forward/backward tilt (pitch) of the subject. After an initial tilt of 10 degrees forward or backward, the subject had to move himself again into the normal position by activating the tilting room via a potentiometer he held in his hand. Each condition was repeated once.

The same test was done with the chair rotated over 90 degrees allowing roll movement of the subject.

These measurements took place in the test battery one time before and two times after the centrifuge run (Tables 2.2 and 2.3).

6.2.2 Stabilometry

A stabilometer platform was used to measure postural stability (Kapteyn and de Wit, 1972). Two stabilometer test stations were used: one was set-up just before the entrance of the centrifuge pit and was used in between the centrifuge runs (see Table 2.1), the other was positioned in the Tilting Room and was used in the Otolith Function Test Battery (see Table 2.2). The test sequence was: standing upright with eyes open (30 seconds), then closing the eyes (60 seconds) followed by a period (60 seconds) of head extension, still with the eyes closed. Video recordings allowed determination of the head angle with respect to gravity. The RMS values of the A/P and the L/R stabilograms were computed.

6.2.3 **Tilting Room**

The TNO Tilting Room was used in the pitch mode. Stimulus freqencies were 0.025 Hz (3 periods), 0.05 (5 periods), 0.1 (5 periods) and 0.2 Hz (5 periods) with an amplitude of the room of 5 degrees. The subject was standing on top of the stabilometer platform which was in a fixed horizontal position. The frequencies of 0.025 and 0.2 Hz were repeated with the subject standing on top of a layer of foamrubber to enhance the effects (Bles and van Raaij, 1988). From the stabilograms the induced body sway at each stimulus frequency was computed (RMS value).

6.3 Results

6.3.1 **Subjective Vertical**

In Fig. 6.1 the results are shown for the pitch and the roll mode, demonstrating a consistent tilt backward after the centrifuge run in the pitch mode and no effect in the roll mode.

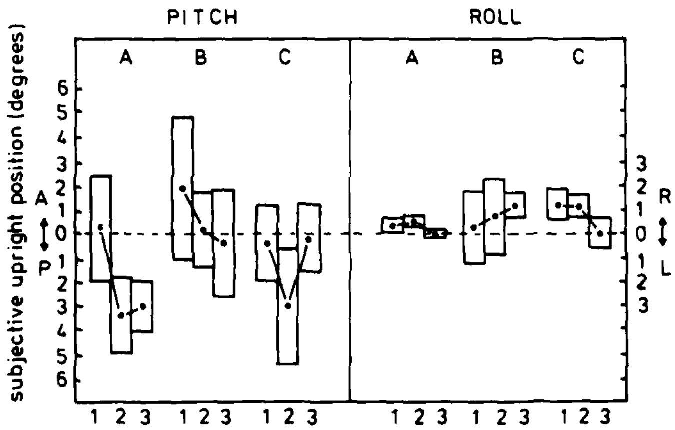

Fig. 6.1 **Mean deviation of the upright position in the pitch mode (left panel) and in the roll mode (right panel) as measured before the centrifuge run and 1 and 6 hours afterwards.**

6.3.2 **Stabilometry**

Postural stability in the 'eyes open' conditions was not affected by the centrifuge run: RMS values of the A/P and the L/R stabilograms were of the same order of magnitude (Fig. 6.2). Closing the eyes resulted in a clear destabilisation of subject B, especially in the A/P direction, reaching its maximum one hour after the centrifuge run. Subjects A and C had no problems in standing upright with the eyes closed, but one hour after the centrifuge run their stability was affected as well, but to a lesser extent.

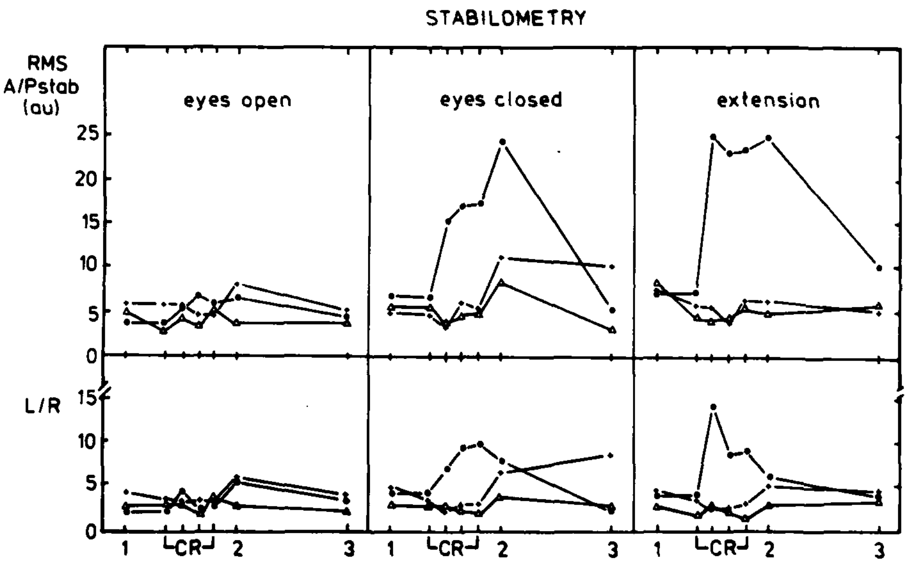

Fig. 6.2 RMS values of the A/P and L/R stabilograms for the conditions 'eyes open', 'eyes closed' and 'head extension, eyes closed' as a function of time (reference time is the stop of the centrifuge run). CR denotes the centrifuge run. Δ, • and + represent subject A, B and C respectively.

The instability in subject B was mainly a tendency to fall backward with subsequent postural corrections. The instability was even worse in the condition with head extension (Fig. 6.2): The RMS values of the A/P stabilograms for subject B were already maximal in this condition after the first half hour centrifuge run. No destabilisation could be observed in subjects A and C. The analyses concerned the period that the head was in extension. From the video recordings it was learned that the amount of head tilt was kept constant during the conditions (a range of about 10 degrees within each subject) but the time to bring the head in extension was during the sessions before the centrifuge run less than one second and increased up to nine seconds after the centrifuge run.

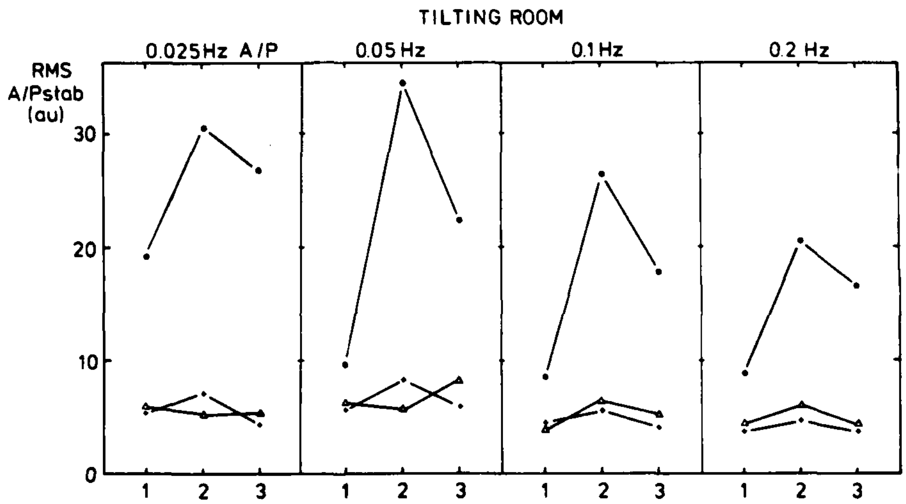

Fig. 6.3 RMS values of the A/P stabilograms obtained in the tilting room for the stimulus frequencies of 0.025, 0.05, 0.1 and 0.2 Hz as measured before and 1 and 6 hours after the centrifuge run (1,2 and 3 resp.). Δ, • and + denote subjects A, B and C resp.

6.3.3 Tilting Room

In Fig. 6.3 the results of the tilting room experiments are depicted, showing the strongest effects for subject B and only minor effects for subjects A and C. The data obtained with the subjects standing on foamrubber showed similar, enhanced effects indeed, but here too no real destabilisation was found in subjects A and C.

6.4 Discussion

A negative after effect of the 3Gx load in the x-direction could explain that in the roll mode no effect and in the pitch mode a consistent backward tilt was found: It could be assumed that during the 3Gx load the internal reference level adapts to a magnitude of up to 3G which means that after the centrifuge run a force into the opposite direction is detected. The vectorial sum of this vector and the gravitational vector is a vector rotated backward with respect to the subject's head. So in the upright position the subject has the feeling of being tilted forward: In an attempt to align his body to the gravity vector he rotates the chair therefore backward. That the angle is only about two degrees should be due to the proprioceptive cues form the contact with the chair: During water immersion greater effects might be expected.

These findings of a backward rotation are also consistent with the tendency of subject B to fall backward as found with the stabilometric measurements. Apparently subjects A and C can concentrate completely on the proprioceptive cues they get from the contact with the stabilometer platform.

Although bringing the head in extension was provocative, the instability was not restricted to the phase of bringing the head in extension, but remained in the steady phase after the head tilt. This suggests that recalibration within the otolith system is the main cause of the affected stability and not an altered interaction of the vertical semi-circular canals and the otolith system. It is of interest to note that the time it took the astronauts to bring the head in extension increased in all astronauts from about 1 up to 9 seconds demonstrating the provocative aspects of this manoeuvre.

The finding in the tilting room that subject B, in contrast to subject A and C, relied heavily on visual information in the readaptation period, is in perfect agreement with the findings in the tilting room following the D1 Spacelab Mission. This suggests similar adaptive behavior for the transition from 0 to 1G as from 3 to 1G.

6.5 Conclusions

The experiments described in this section suggest changes in otolith functioning in the period after the centrifuge run. These changes were still visible six hours after the run. The effects were mainly in the midsagittal plane: Backward tilt of the subjective vertical for all subjects and falling backward for one subject together with a larger body sway in the tilting room. The similarity with the findings obtained fron the same subjects immediately after the D1 Spacelab Mission suggests that the same mechanisms are involved in both readaptation periods.

7 OPTOKINETIC NYSTAGMUS MODULATION BY LINEAR ACCELLERATION.

J.T. Marcus and J.E. Bos

7.1 Introduction

Eye movements induced by linear acceleration show a considerable lower gain than eye movements induced by rotatory movements. However, distinguished modulation of the OptoKinetic Nystagmus Slow Phase Velocity (OKN-SPV) by a sinusoidally varying linear acceleration has been shown by Buizza (1980). It was hypothesized that this otolith induced effect would be affected by long duration Gx load when the subject's x-axis would be aligned to the gravitational vector (supine position).

7.2 Methods

Before and two times after the centrifuge runs (Tables 2.2 and 2.3) the three subjects were subjected to optokinetic stimulation, 70 deg/s to the right or left relative to the subject's head. The subjects were in supine position on the SLED (Fig. 7.1) and after 20 seconds of pure optokinetic stimulation they were moved laterally in order to investigate the SPV modulation of the OKN by linear acceleration. The SLED moved sinusoidally

Fig. 7.1 General set-up: Shown are the linear accellerator (SLED) with the subject in supine position, the legs folded upward. Fixed to the chair above the subjects head a screen is mounted on which a rotating vertical bar pattern is projected (moving left-right and right-left with respect to the subject's head.

(freq. 0.18 Hz, maximal acceleration approx. 0.2G). Nystagmus Slow Phase Velocity was computed by means of a semi-interactive computer program, allowing rejection of artefacts in the recordings. On the final SPV files a Fast Fourier Transform analysis was done in order to determine the amplitude A_m (half of the peak-to-peak value) of a possible modulation at the Sled frequency.

7.3 Results

A modulation of the OKN-SPV at the Sled frequency was observed in about 50% of the conditions where the Sled was moving: In the pure optokinetic conditions this modulation was not found. Due to the analysis procedure a variation of about 15 % in the modulation depth A_m should be taken into account. It is shown in Table 7.1 that the centrifuge run has no systematic influence on the modulation.

Table 7.2 Modulation amplitude A_m (degr/s)of the OKN SPV due to the Sled movement before, and two times after the 3Gx centrifuge runs. Parentheses denote values that do not exceed the noise level for each measurement condition.

	Subject A	Subject B	Subject C
pre centrifuge run	7.6	(1.6)	4.1
one hour after centrifuge run	4.5	2.7	6.2
five hours after centrifuge run	(2.6)	(5.2)	(1.4)

7.4 Conclusions

Apparently the OKN-SPV modulation in our experimental set-up is not as obvious as in the set-up of Buizza (1980). This inhibited more accurate determination of a possible change in OKN-SPV modulation by the 3Gx load. Supplementary experiments should be performed to get more distinct OKN-SPV modulation.

8 TASK PERFORMANCE

C.J.E. Wientjes

8.1 Introduction

The success of a Spacelab mission relies on performance effectiveness and crew well-being, which may be disturbed by space motion sickness.
The main question in this test was whether adaptation problems after the prolonged G-load would affect task performance. In order to assess this, task performance upon the Double Task (see 8.2) was measured prior to the centrifuge runs, immediately afterwards, and after several hours (Tables 2.2 and 2.3).

8.2 Method

8.2.1 Task

In this study the Double Task from the Taskomat Task Battery (Boer et al., 1987) was used. This task consists of a Tracking Task and a Continuous Memory Task (CMT). Both tasks were visually presented to the subject by means of a monitor, which was placed in front of him. The Double Task was presented in three parts, each of a duration of seven minutes: A) a Tracking part, B) a CMT part, and C) a Tracking plus CMT part. Therefore, the total duration of the task was 21 minutes. Tracking performance was measured in terms of the RMS of the distance between the track and the gate which was controlled by the joystick; CMT task performance was measured in terms of the percentage of counting errors.

8.2.2 Procedure

Upon arrival in the laboratory for the Otolith Function Test Battery I, the subjects were trained first on the task. Training consisted of one 7-minute period of the Tracking task, and one 7-minute period of the CMT task. The tracking plus CMT part was not presented during the training period.

Three complete 21-minute task sessions were presented during the study: prior to the centrifuge runs (Baseline 1), immediately after the centrifuge runs (Exp), and several hours after the centrifuge runs (see Table 2.3).

8.3 Results

The overall results showed no clearcut effects of G-adaptation upon performance (see Fig. 8.1 and 8.2), although the mean error percentage of the CMT in the tracking plus CMT part appeared to be somewhat enhanced in the Exp condition, compared to both Baseline conditions. However, this difference is very small and well within the SD-range. As is apparent from the magnitude of the SD's the data show great individual differences. These were due to the differences between the subjects in their general performance levels, and to the differences between the subjects with respect to the effect of the G-load. In addition to the slight decrease in CMT performance in the Exp condition, that was described above, the tracking performance of one subject appeared to be affected by the G-load. In the Exp condition, this subject's single tracking RMS score was 6.72, compared to 6.57 and 6.15, respectively, in the Baseline 1 and 2 conditions. This effect was not found with the other two subjects.

8.4 Discussion

Although some minor effects of exposure to a prolonged G-load might be present in these data, an evaluation of these results is hampered by the differences in individual performance. As a consequence, it is not apparent whether these effects were due to random noise, or to the G-load. Another difficulty is, that the data of two of the three subjects do not show the pattern that is normally found with the Double Task: a deterioration of both tracking and CMT performance during the combined tracking/CMT period, with respect to the single task periods (Boer et al., 1987). This effect is believed to be due to capacity limitations (Jorna, 1982). It seems possible that insufficient training on the task prior to the experiment is the cause of some of these problems.

It must be concluded that the results do not show that adaptation problems subsequent to a prolonged G-load have a systematic effect upon task performance.

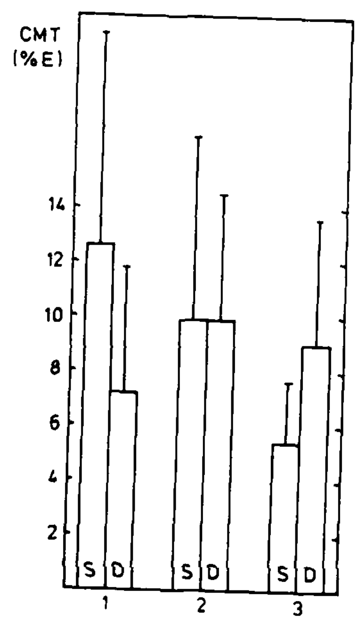

Fig. 8.1 Performance on the CMT in percentage error of recall. S - single task period; D - combined tracking/CMT period.

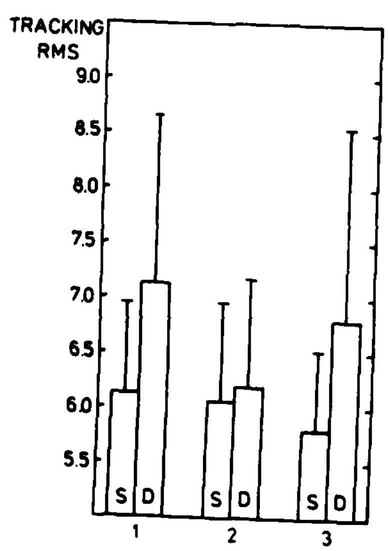

Fig. 8.2 Tracking performance (RMS). S - single task period; D - combined tracking/CMT period

9 CALORIC EXAMINATION

W.J. Oosterveld and H.W. Kortschot

9.1 Introduction

The caloric vestibular test stimulates the horizontal canal on one side, which results in a nystagmus. This nystagmus, accompanied by a rotation sensation, is the result of a convective movement of endolymph in the horizontal canal. This endolymph flow is assumed to be the major source of caloric nystagmus.

Studies of the effect of body position have produced effects which cannot be explained by a convective endolymph movement. The duration of the nystagmus in face-up position is greater than in face-down position (McNally et al., 1947). Furthermore, the two points of reversal of the nystagmus response do not lie 180° apart (Behrman, 1942) which suggests otolithic influences.

Unexpected contradictions in the strength of the nystagmus when the effects of prone and supine positions were compared did not support the assumption that a cupula-gravity interaction was likely (McLeod and Correia, 1964). The most provocative position for the caloric test is lying on a stretcher, the head with a 30° tilt up (Brünings, 1911; Coats and Smith, 1967; Jongkees, 1949). These authors suggest that the otolithic system is involved in the genesis of a caloric nystagmus.

Scherer et al. (1986) reported about caloric nystagmus provoked in Spacelab I. However, Oosterveld et al. (1985) described that a caloric nystagmus disappeared during shortlasting microgravity in parabolic flight. Hood (1989) reinterpreted previous caloric experiments and made clear that direct thermal action upon the endorgan remains the main cause for a caloric nystagmus.

The aim of the application of the caloric test in the present study was to get information about the least provocative head position before and after the centrifuge run. When these results differ the assumption of an otolithic component in the generation of caloric nystagmus is likely. Furthermore it would suggest that a linear acceleration sustained for 90 min changes the influence of the otoliths on the canals.

9.2 Method

The astronauts were subjected to the caloric test with cold water (30 °C) on one ear for about 10 minutes.

Horizontal and vertical eye movements were recorded and a video recording was made of the position of the head in space.

During the calorization the astronauts had to bend their head slowly forward and backward in order to find the position with the least vertiginous sensation. They did this first with the eyes closed, then with open eyes. The test was conducted before the centrifuge run, and 2 and 6 hours after the run (Tables 2.2 and 2.3).

9.3 Results

The results are shown in Table 9.1. The angles of the head are given with reference to the head position during the 'eyes open' condition of the stabilometry.

Table 9.1 The angle (degrees) of head extension (with respect to the normal upright head position) where the subjects had no sensation of rotation during calorization as found before, two hours and six hours after the centrifuge run. The Nystagmus SPV was always 0°/s except for the values given within brackets.

	Subject A		Subject B		Subject C	
	eyes closed	eyes open	eyes closed	eyes open	eyes closed	eyes open
pre centr. run	60	50	34	60	19 (3°/s)	- (3°/s)
two hours after centrifuge run	12	25	19 (2°/s)	55 (7°/s)	10 (3°/s)	25 (3°/s)
six hours after centrifuge run	42	55	24	40	22 (3°/s)	20 (3°/s)

9.4 Conclusions

In all astronauts the neutral position proved to have a smaller angle with the vertical when the eyes were closed than when they were open.
Immediately after the run the angles became smaller in all subjects, which meaned that they held their heads more in the upright position than before. Six hours later the angles increased, but not up to the pre-run values.
It is most likely that the otoliths play a major role in the found phenomenon. The hours with a G-load have modified the response of the horizontal canal. This response obtains its maximum at an angle wherein the otoliths of the utricle are more situated in the upright position.
The fact that conditions 'eyes open' and 'eyes closed' differ with regard to the angle of least sensation suggests a visual-vestibular input component.

The recovery to the pre-run values is not reached within 6 hours. This slow action corresponds to the subjective feelings of 'well-being' which exceeded the 6 hours period. This long lasting effect supports the assumption that central adaptation mechanisms play also some role.

10 SUMMARY AND DISCUSSION

For the astronauts involved in the present experiment the motion sickness following the centrifuge run was quite a surprise: On a previous occasion during their astronaut training they had been subjected to 3Gz stimulation for about 20 minutes but that caused no after effects similar to the after effects obtained in this experiment. Most probably the stimulation along the x-axis has been crucial in evoking the effects since after stimulation of 30 minutes of 3Gx the readaptation effects were already clearly recognizable and would have been visible after 20 minutes of 3Gx stimulation as well. In further experiments differences between the x-, y-, and z-direction should be explored, the more so since at launch of the STS the astronauts are exposed to a 3Gx stimulus for a period of 8 minutes which might have a negative effect to the astronauts subsequent well-being in view of the present findings.

An important result of the present study is that the involved astronauts were all of the opinion that the readaptation effects were very similar to the Space Adaptation Syndrome. Moreover, they agreed that the rank order of their susceptibility to the Space Adaptation Syndrome was the same as for the centrifuge induced sickness. It may be postulated therefore that the method presented in this study is a model to simulate the Space Adaptation Syndrome on earth.

Practical consequences of this finding may be that future astronauts can be made familiar with the Space Adaptation Syndrome already before their space flight. Moreover, if repeated exposure would lead to a reduction of the resulting sickness, and if this adaptation would hold in space, than a major step forward in the research on space sickness has been made.

The mechanisms involved in the generation of the readaptation sickness are still unclear. In view of the cardio-vascular data, however, it is highly probable that the sickness is not of cardiovascular origin and therefore of vestibular origin. Changes in vestibular (otolith) functioning have been found indeed, but the changes were not always conform the hypotheses. In the tests on spatial perception, postural stability and caloric irrigation effects, changes were found as expected within the midsagittal plane. In the test in visual motion perception, however, no effect along the x-axis was found which was against the hypothesis. It was also quite surprising that movements along the subject's z-axis parallel to gravity (heave) were found to be so provocative whereas movements along the x-axis in the horizontal plane did not particularly bother the subjects. New concepts on vestibular functioning should be developed in order to explain all these findings together.

It may be assumed that the sickness after the centrifuge run is due to adaptation phenomena within the central otolith system. It may be assumed therefore that extension of our knowledge of the functioning of the (central) otolith system enhances our understanding of motion sickness in general, since most motion sickness inducing conditions comprise otolith stimulation and the correlation between motion sickness susceptibility and the outcome of vestibular laboratory tests is still rather poor.

11 CONCLUSIONS

1. It is possible to simulate the Space Adaptation Syndrome by a long duration G load along the subject's x-axis. After a centrifuge run of 3Gx for 1.5 hours the astronauts recognized symptom. which were similar to the Space Adaptation Syndrome.
2. These motion sickness effects outlasted the centrifuge stimulation for a long time (in the present experiment with 3Gx during 1.5 hours the effects remained for at least 6 hours).
3. The susceptibility of the astronauts for the centrifuge induced motion sickness corresponded to their susceptibility for the Space Adaptation Syndrome.
4. The centrifuge induced motion sickness is of vestibular origin: The otolith function test battery yielded changes after the centrifuge run. Six hours after centrifuge loading the astronauts still had not reached their baseline values in most tests. Stabilometry and the tilting room examination yielded results similar to those obtained during the Spacelab D-1 Mission.

ACKNOWLEDGEMENTS

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REFERENCES:

von Baumgarten, R.J., Benson, A., Berthoz, A., Bles, W., Brandt, Th., Brenske, A., Clarke, A., Dichgans, J., Eggertsberger, R., Jurgens, K., Kass, J., Krafczyk, S., Scherer, H., Thümler, R., Vieville, Th., Vogel, H. and Wetzig, J. (1987). European experiments on the vestibular system during the spacelab D1 mission. In: Proceedings of the Nordeney Symposium, Aug 27-29, 1986 "Scientific results of the German spacelab mission D1", 477-490.

Behrman, W. (1942). Über Indifferentzlagen und Nystagmusgebiete. Acta Otolaryngol. 30, 298-310.

Bles, W. and van Raay, J.L. (1988). Pre- and Postflight (D-1) postural control in tilting environments. Adv. Oto-Rhino-Laryngol., 42:13-17.

Boer, L.C., Gaillard, A.W.K. and Jorna, P.G.A.M. (1987). Taskomat: een batterij van informatieverwerkingstaken. Report IZF 1987-2, TNO Institute for Perception.

Brandt, Th., Krafczyk, S. and Malsbenden, J. (1981). Postural imbalance with head extension: improvement by training as a model for ataxia therapy. Ann. NY Acad. Sci. 374:636-49.

Brünings, H. (1911). Beiträge zur Theorie, Methodik und Klinik der kalorimetrischen Funktionsprüfung des Bogengangsapparates. Ztschr. f. Ohrenh. 63: 20.

Buizza, A., Leger, A., Droulez, J., Berthoz, A. and Schmidt, R. (1980). Influence of otolithic stimulation by horizontal linear acceleration on optokinetic nystagmus and visual motion perception. Exp. Brain Res. 39:165-176.

Coats, A.C. and Smith, S.Y. (1967). Body position and the intensity of caloric nystagmus. Acta Otolaryngol. 63, 515-532.

Cogoli, A., Bechler, B., Müller, O. and Hunzinger, E. (1986). Effects of microgravity on lymphocyte activation Proceedings of the Nordeney Symposium, Aug 27-29, 1986:366-375.

Graybiel, A., Wood, C.D., Miller II, E.F. and Cramer, D.B. (1968). Diagnostic criteria for grading the severity of motion sickness. Aerospace Med., 39:453-455.

Homick, J.L., Reschke, M.F., and Vandenploeg, J.M. (1984). Space Adaptation Syndrome: Incidence and operational implications for the Space Transportation System Program. in: Motion Sickness: Mechanisms, Prediction, Prevention and Treatment. Agardograph 372 36 - 1-6.

Hood, J.D. (1989). Evidence of direct thermal action upon the vestibular receptors in the caloric test. Acta Otolaryngol. 107: 161-165.

Hosman R.J.A.W. and van der Vaart J.C. (1989). Motion perception and vehicle control. In: R. Warren and A.H. Wertheim (eds) The perception and control of ego motion. Earlbaum, New York (in press).

Jongkees, L.B.W. (1949). Which is the preferable method of performing the caloric test. Arch. of Otolaryng. 49, 594-608.

Jorna, P.G.A.M. (1982). Stress, information processing and coping with depth: Problems of individual divers. Report IZF 1982-14, TNO Institute for Perception.

Kapteyn T.S. and de Wit, G. (1972). Posturography as an auxiliary in vestibular investigation. Acta Otolaryng. (Stockh.) 73, 101-111.

Lorenzi, G., Fuchs-Bislin, P. and Cogoli, A. (1986). Effects of hypergravity on "whole-blood" cultures of human lymphocytes. Aviat. Space Environ. Med. 57:1131-1135.

Matin, L. (1982). Visual localization and eye movements. In: A.H. Wertheim, W.A. Wagenaar and H.W. Leibowitz (eds): Tutorials on motion perception, (pp 101-156). Plenum New York.
McLeod, M.E. and Correia, M.J. (1964). Use of caloric test in evaluating the effects of gravity on cupula displacement. US-Navy report: NSAM-889.
McNally, W.J., Stuart, E.A., Jamieson, J.S. and Gaulton, G. (1947). Some experiments with caloric stimulation of the human labyrinth to study the relative values of ampullo-petal and ampullo-fugal endolymphatic flow (Ewald's law). Trans. Am. Acad. Ophthal. Otolaryng. 52:513-517.
Mittelstädt, H. (1989). Basic solutions to the problem of headcentered visual localization. In: R. Warren and A.H. Wertheim (eds): The perception and control of self-motion. Earlbaum, New York. (in press).
Ockels, W.J., Furrer, R. and Messerschmid, E. (1989). Simulation of the Space Adaptation Syndrome on earth. Subm. to Nature.
Oman, C.M., Lichtenberg, B.K., Money, K.E. and McCoy, R.K. (198[illegible]) M.I.T./-Canadian vestibular experiments on the Spacelab-1 mission: 4. Space motion sickness: symptoms, stimuli, and predictability. Exp. Brain Res. 64:316-334.
Oosterveld, W.J., Greven, A.J., Gürsel, A.O. and de Jong, H.A.A.(1985). Caloric vestibular test in the weightless phase of parabolic flight. Acta Otolaryngol. 99:571-576.
Reschke, M.F., Homick, J.L., Ryan, P. and Moseley, E.C. (1984). Prediction of the Space Adaptation Syndrome. In: Motion Sickness: Mechanisms, Prediction, Prevention and Treatment. Agardograph 372 26 - 1-19.
Scherer, H., Clarke, A.H., Brandt, U., Merbold, U. and Parker, R. (1986). Caloric nystagmus in microgravity. In: European vestibular experiments in the Spacelab-1 Mission. Exp. Brain Res. 64:255-263.
Sperry, R.W. (1950). Neural basis of the spontaneous optokinetic response produced by visual inversion. Journal of Comp. and Physiol. Psychol., 43, 482-489.
Thornton, W.E., Moore, T.P., Pool, S. and Vanderploeg, J. (1987). Clinical characterization and etiology of space motion sickness. Aviat. Space Environ. Med. 58 (9, Suppl.):A1-8.
Wertheim, A.H. (1981). On the relativity of perceived motion. Acta Psychol. 48, 97-110.
Wertheim, A.H. (1987). Retinal and extraretinal information in movement perception: how to invert the Filehne illusion. Perception 16, 299-308.
Wertheim, A.H. (1989). Visual, vestibular and oculomotor interactions in the perception of object motion during ego motion. In: R. Warren and A.H. Wertheim (eds): The perception and control of ego motion. Earlbaum, New York. (in press.).
Wertheim, A.H. and Bles, W. (1984). A reevaluation of cancellation theory: Visual, vestibular and oculomotor contributions to perceived object motion. Report IZF 1984-8, TNO Institute for Perception.
Wertheim, A.H., Van Gelder, P., Lautin, A., Peselow, E. and Cohen, N. (1985). High thresholds for motion perception in schizophrenia may indicate extraneous noise levels of central vestibular activity. Biol. Psych., 20, 1197-1210.
Young, L.R., Oman, C.M., Watt, D.G.D., Money, K.E., Lichtenberg, B.K., Kenyon, R.V. and Arrott, A.P. (1986). M.I.T./Canadian vestibular experiments on the Spacelab-1 mission: 1. Sensory adaptation to weightlessness and readaptation to one-g: an overview. Exp. Brain Res. 64 nr.2: 291-298.

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

The three European scientist astronauts of the D1 Spacelab Mission were exposed to a 1½ hours +3G centrifuge run in supine position resulting in a linear acceleration along the x-axis (3Gx). Afterwards they experienced motion sickness symptoms which were for each of the astronauts similar to the symptoms of the Space Adaptation Syndrome as experienced during their space flight in 1985. These motion sickness symptoms lasted up to 6 hours. In otolith function tests following the centrifuge run, changes in visual-vestibular interaction were observed which replicated findings obtained immediately after their space flight.

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